National Aeronautics and
Space Administration

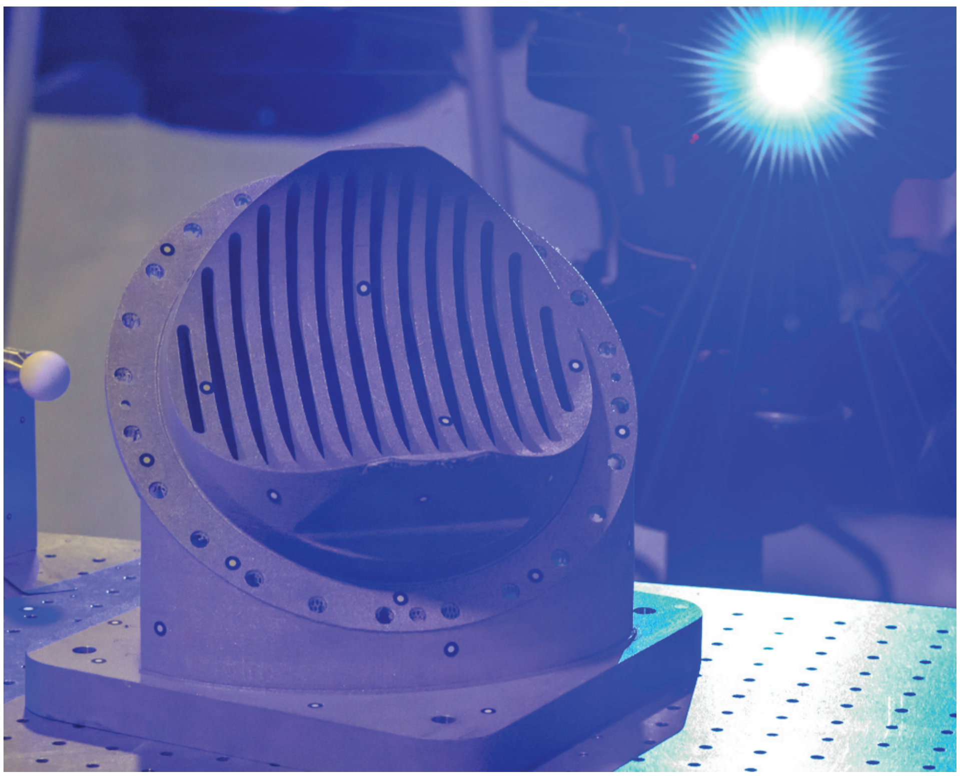
Advanced Manufacturing

Pioneering Affordable Aerospace Manufacturing

Rapidly evolving digital tools, such as additive manufacturing, are the leading edge of a revolution in the design and manufacture of space systems that enables rapid prototyping and reduces production times. Marshall has unique expertise in leveraging new digital tools, 3-D printing, and other advanced manufacturing technologies and applying them to propulsion systems design and other aerospace materials to meet NASA mission and industry needs. Marshall is helping establish the standards and qualifications "from art to part" for the use of these advanced techniques and the parts produced using them in aerospace or elsewhere in the U.S. industrial base.

At-A-Glance

Propulsion system development requires new, more affordable manufacturing techniques and technologies in a constrained budget environment, while future in-space applications will require in-space manufacturing and assembly of parts and systems. Marshall is advancing cutting-edge commercial capabilities in additive and digital manufacturing and applying them to aerospace challenges. The center is developing the standards by which new manufacturing processes and parts will be tested and qualified.



Selective laser melting enables faster and cheaper component development.

Accelerating Design and Development of Propulsion Systems

As designers learn the capabilities of Advanced Manufacturing, the way they think is changing. The ability to rapidly create and test prototypes saves significant time between design cycles, as design concepts can quickly advance from drawings to test articles. A propulsion system sub-assembly that previously required multiple welds might now be 3-D printed all as one piece and test fired in less time and at much less cost than traditional manufacturing. A combination of experienced engineers and in-house resources enables Marshall to take a project from conception through manufacturing, finishing, and testing, resulting in flight-ready hardware and/or proven processes for use by partners during full-scale production.

Marshall houses a complete suite of digital manufacturing and support capabilities, including Structured Light Scanning, Non-Destructive Evaluation, Manufacturing Simulation, Manufacturing Planning and Execution, and inspection and machining technologies.

This one-piece injector took just 40 hours to make with a 3-D printing machine, instead of the months needed by traditional manufacturing.

Advancing Manufacturing Technology for Future Needs

Marshall became involved in Additive Manufacturing when it was still an emerging technology and purchased one of the first printers in 1990, primarily for rapid prototyping. Today, the center team is using state-of-the-art 3-D printers that work with a variety of plastics and metals, including titanium, aluminum, Inconel and other nickel alloys widely used in aerospace manufacturing. In addition to its focus on manufacturing future propulsion systems, the Center is leading efforts to demonstrate 3-D printing technology in orbit — the first step toward in-situ resource utilization on orbit or at exploration destinations, a critical need for future long-duration and deep-space missions.

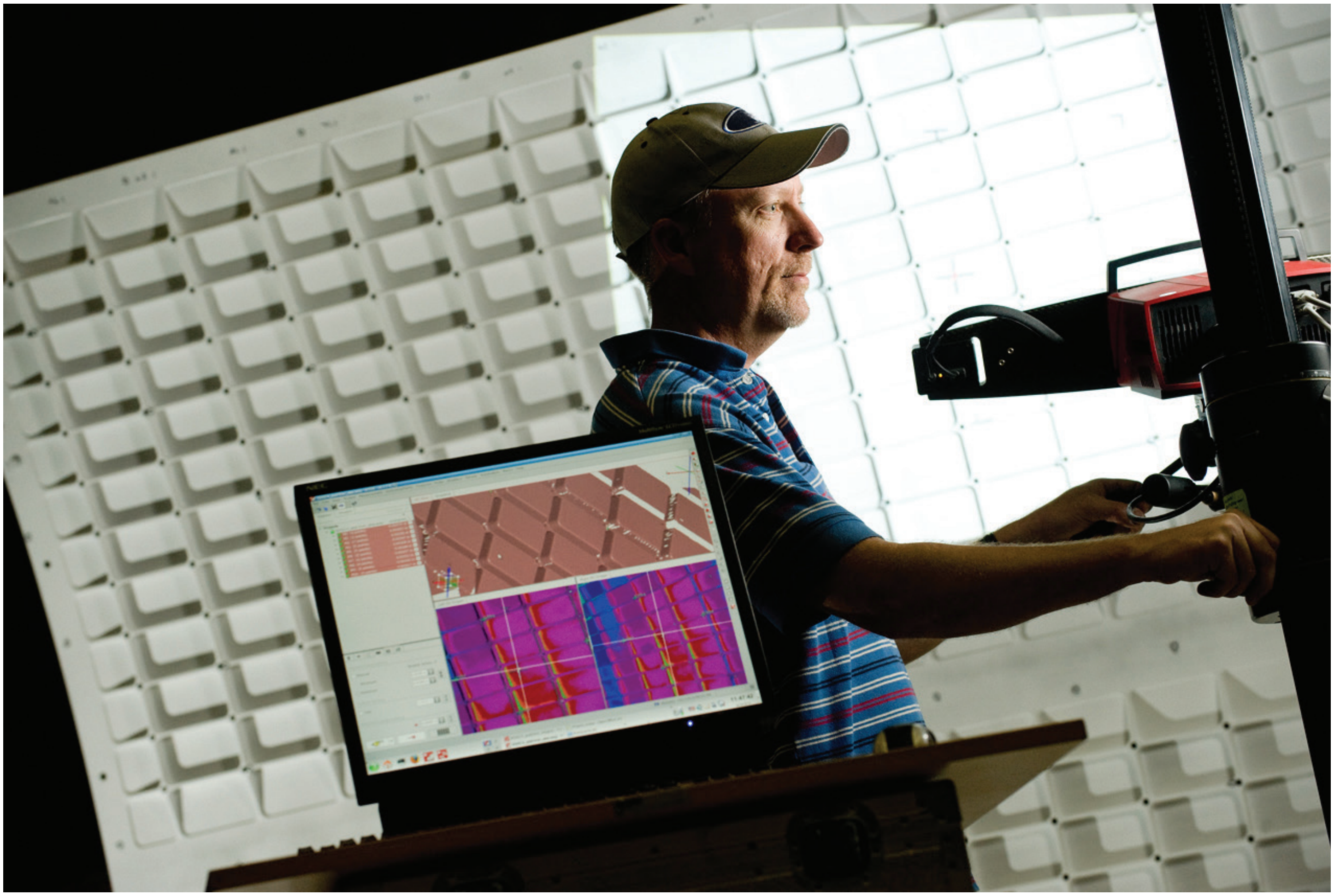
Additive Manufacturing technology for metals includes:

- Selective Laser Melting (Direct Metal Laser Sintering)
- Electron Beam Melting

Additive Manufacturing technology for plastics includes:

- Stereolithography (often used for flow cell models and cold flow testing, as the parts are water resistant and can be made see-through to channels inside)
- Fused Deposition Modeling (an extrusion-based technology that is gravity-independent and holds potential for development of in-space manufacturing)

Structured Light Scanning is also used to evaluate parts produced by 3-D printers or other methods by scanning and comparing the as-built version to the original computer design. Marshall teams working on two Orion Multipurpose Crew Vehicle Stage Adapters used it to show where large panels needed to be cut to precisely shape the 18-foot-diameter cone, saving millions of dollars on custom tooling. The technique was also used to scan heritage F-1 engines, and the scans were then used to fabricate needed tooling to disassemble the engine for testing.



Structured Light Scanning of Orion panels allows extremely precise fits, saving millions of dollars on custom tooling.

Structured Light Scanning technology includes:

- One Blue Light "Triple Scan" and other Blue Light 3-D Scanners
- White Light 3-D Scanners

The capability allows for scanning almost anything, from items smaller than a dime to the size of a Boeing 747. It has been used to scan 40-foot-diameter barrel sections of a space shuttle external tank and Space Launch System tank sections.

Other scanning and Non-Destructive Evaluation inspection technology includes:

- Computed Tomography (CT) scanning
- Radiography
- Photogrammetry
- Ultrasonic techniques
- Electromagnetic techniques
- Dye penetrants

Scanning works in concert with other digital manufacturing techniques such as manufacturing simulation to identify and address potential problems early in the design and production process, saving time and costly re-tooling or repair. The expertise and software available at Marshall can provide virtual fit checks, predict the buildup of material on a surface, reverse engineering, kinematic analysis, and much more.

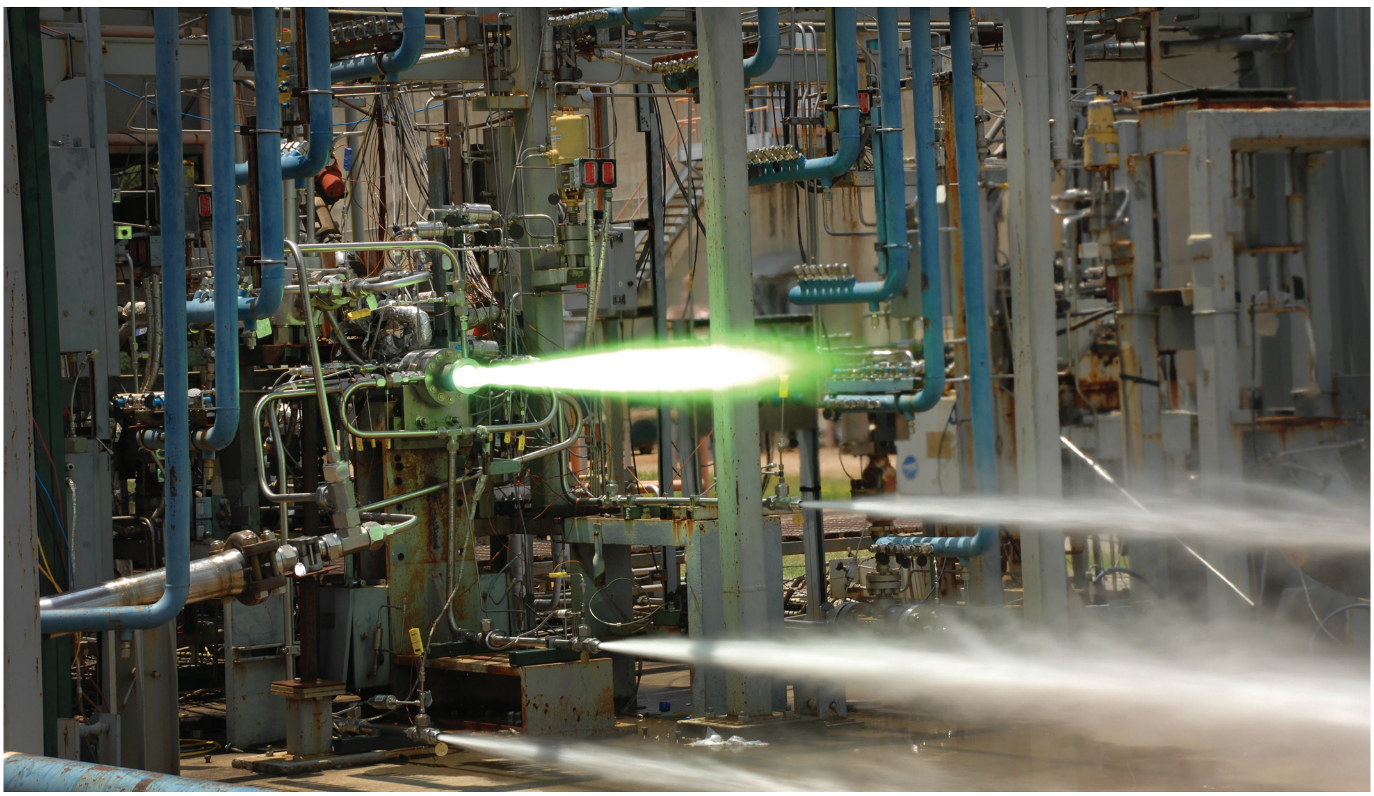
Printing Propulsion Cuts Cost and Schedule

It looked like just another rocket test, one of thousands at Marshall Space Flight Center over the decades. But the firing on June 11, 2013, was a milestone — it was the first involving a rocket engine fuel injector that had been designed, 3-D printed in one piece, and hot-fire tested completely in-house at Marshall.

The Propulsion Systems Department designed the injector, which the Materials and Processes Laboratory 3-D printed in one piece by sintering Inconel steel powder in a process called Selective Laser Melting. It took only 40 hours to print each of two injectors. Then came minimal machining and inspection by scanning.

Using traditional methods, this would have taken six months to fabricate, with four parts, five welds, detailed machining, and a price tag of more than $10,000 per injector. Instead, it took just about a month for the 3-D-printed injectors to go from designs on a computer screen to parts in the line of fire during a series of Space Launch System acoustic tests, at a cost of less than $5,000 per injector.

Engineers compared the performance of the 3-D-printed injectors to those produced with multiple parts and traditional welds, and saw no difference in performance. In fact, post-test inspection of the printed injectors found them in such excellent condition that plans are for them to be re-used in upcoming tests.



Marshall's 3-D printed injectors were produced at half the cost and six times faster than traditional manufacturing.

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